



Arizona Grain Research & Promotion Council

Project Title & number	Measuring Evapotranspiration of Desert Durum at Multiple Scales (18-03)
Project Timeline	October 1, 2017 – December 31, 2018
Principal Investigator	Paul Brierley Yuma Center of Excellence for Desert Agriculture University of Arizona
Co-Investigator(s)	Dr. Charles Sanchez Soil, Water, and Environmental Sciences University of Arizona
Cooperating Investigator(s)	Dr. Andrew French USDA-ARS Arid Lands Agricultural Research Center

Introduction

Durum wheat produced in the desert is established (germinated) by either planting into the soil moisture (shortly after a pre-irrigation), sprinkler irrigation after seeding, or by basin surface irrigation after seeding. After stand establishment all wheat is irrigated by basin surface irrigation. Paramount to efficient irrigation management is accurate estimation of wheat evapotranspiration (ET) and the tools to use these estimates. Irrigation application time is determined by the allowable depletion of available water within the soil profile to avoid yield loss. Required irrigation depth is determined by the amount required to refill the water lost from the soil profile by ET.

The depletion of soil moisture by crops can be measured directly by soil sensing devices or estimated from weather-based ET measurements. Where ET_c is calculated from ET_o and crop coefficients (k_c), and ET_o is calculated using weather-based equations (e.g. Penman-Monteith or others). We have developed, and are continuing to develop, criteria for scheduling irrigations in the desert (Martin et al., 2003; Brown, 2005). However, work is needed to develop crop coefficients for wheat for planting dates from November through early March.

Over the past decade there have been significant advances in technologies to measure crop ET under field conditions. One such technology is Eddy Covariance (ECV). Eddies are turbulent airflow caused by wind, the roughness of the Earth's surface, and convective heat flow at the boundary between this surface and the atmosphere. ECV measures two distinct turbulent components: sensible heat flux and latent heat flux. Sensible heat flux represents energy transport due to temperature gradients between soil, plants and the overlying air. Sensible heat is positive when upward moving eddies are warmer than downward moving eddies. Latent heat



flux represents transport due to water phase change from liquid to gas and is the energy representation of ET. Positive latent heat flux occurs when water vapor in upward moving eddies is greater than in downward moving eddies; for the opposite condition, negative latent heat flux represents condensation. Water vapor, heat, and carbon dioxide transferred by eddies can be measured directly using ECV.

The ECV method is now a well-established, standardized, and state-of-the-art approach for measuring ET and results from ECV stations are considered reference quality. Nevertheless, ECV data have some shortcomings. ET values are locally, but not regionally, representative of environmental water fluxes. Second, ET values have a variable geographic footprint which is dependent upon uncontrollable wind speed, wind direction effects. These shortcomings mean that ET assessments over multiple farms and heterogeneous landscapes are difficult and potentially biased. An approach that can help remove errors and bias is Large Aperture Scintillometry (LAS), a technique that allows ET measurements to be scaled up over space and time. Thus, field estimates should be less susceptible to local bias and varying flux footprint, which in turn means that estimates from diverse cropping systems can be measured concurrently over scales approaching 5 kilometers. Thus, we will use LAS methods to augment our ECV methods.

Finally, there have been recent developments in the use of satellite imagery to estimate ET. Such imagery has the potential to map ET across entire irrigation districts at fine spatial and temporal resolution without some of the constraints imposed by ECV systems. However, ET mapping with satellite data has either been too infrequent or too coarse in resolution to be practical. Starting last year these limitations began to be removed with the availability of satellite data from Landsat, Sentinel 2, Venus, and ECOSTRESS. High resolution (5-60m) data have become available in 2-7-day intervals. These data, as well as more local estimates discussed above, can be made available to growers as mobile APP management tools. This approach is aimed at addressing AGRPC's #1 research priority "Reduction in fresh water consumption" by collecting the data required to develop water management tools for Durum wheat.

Methods

In order to meet the objectives of this project, we collected data at multiple scales (ECV, LAS, Satellite) across a wide range of planting dates. Data were collected on two production sites in 2016-2017 and four grain production sites during 2017-2018 (Table 1). ET data were collected during the entire production period using Eddy-Covariance (ECV) methodology (Figure 1).

In 2017-2018 we augmented our ECV measurements using Large Aperture Scintillometry (LAS) (Figure 2). LAS is an established methodology for accurately measuring sensible heat flux (H) over 1-5km distances, a scale range greatly exceeding typical distances observed for H flux data collected with eddy covariance systems, 100-200m typical for deployment at 2m heights above crops. However, LAS approximates ET using residuals in energy balance calculations.



Monitoring of fractional cover and leaf area over crops in the Yuma region was done by processing Sentinel 2, Venus, and Landsat 8 satellite data tiles (Figure 3). Sentinel 2 are observations provided by the European Space Agency; Landsat are provided by the U.S. Geological Survey. Data were obtained through the USGS EarthExplorer portal (<https://earthexplorer.usgs.gov>) and through the CNES Theia portal (<https://theia.cnes.fr>). The data processing steps are as follows:

1. Identify geographic area of interest, time span, and satellite products on EarthExplorer website.
2. Select cloud-free scenes using image thumb-nails and order for bulk download.
3. Download geotiff formatted data using the USGS-provided Bulk Download Application
4. Read, convert satellite data to NDVI using an in-house R-script.
5. Extract median NDVI values in target fields of interest using an in-house R-script and plot polygons in shapefile format.

Data plotted are top-of-atmosphere, 10-meter resolution, normalized difference vegetation indices (NDVI) taken from infrared and near-infrared channels, bands 4 and 8, observed by the Sentinel 2A and Sentinel 2B satellites. Venus satellite data wasn't available for the Yuma region during the time frame of this study.

Results

Evapotranspiration (ET)

Daily and cumulative ET are shown in Figures 4 through 9. ET on any given day can vary depending on soil moisture conditions and ambient weather (temperature, humidity, wind). However, all sites showed a similar pattern where daily ET generally increased as the crop approached maturity and then declined rapidly during senescence. Seasonal ET for Durum wheat ranged from 22 to 27 inches across the sites. We are continuing to process the LAS data streams, but they are not complete as of the reporting. We anticipate completing these data during the 2018-19 AGRPC-funded third year of this project in order to further validate our satellite ET estimation model.

NDVI

The aim of using NDVI time-series data is to create high resolution, field-specific, time-series maps that can be used to chart existing crop cover and help forecast crop water use. NDVI is closely correlated to leaf area and can be converted to site-specific crop coefficients. Knowing crop ET coefficients and reference evapotranspiration - obtained from local weather data - one can then obtain standardized crop evapotranspiration maps at frequent intervals. However, a project objective includes development of satellite-based evapotranspiration (ET) maps that represent crop status under all conditions, and for this purpose we are in the process of incorporating thermal infrared satellite data - Landsat 8 and ECOSTRESS - to allow detection of crop water stress. This is feasible because plants show anomalously high temperatures when their



water status is insufficient for normal growth. By combining surface temperature and NDVI data streams, we will create daily estimates of current and near-term forecasts of crop ET. Ecostress' launch was delayed until June, 2018 – too late to utilize during the 2017-2018 grain growing season. We are collecting additional data in 2018-2019 and plan to test alternative ET models with our entire data base during the 2018-2019 AGRPC-funded third year of this project.

Future Plans

Additional data will be collected at multiple scales on Durum wheat and barley in central Arizona in the 3rd year of this AGRPC-funded project, giving us a more complete database. We will use this data to calibrate and validate the satellite algorithm which is being developed. Having this robust dataset will improve understanding of both crop water use and the water/salt balance of a vegetable/wheat rotation.

Table 1. Field sites used to collect wheat ET data in 2016 through 2018.

Station Label	Field	Planting Dates	Deployment Dates	Station Removal	Harvest Dates
ALARC 1	YID 16-17	Dec 13, 2016	Dec 14, 2016	May 5, 2017	May 6, 2017
ALARC 2	YCWUA 16-17	Jan 11, 2017	Jan. 12, 2017	Jun 1, 2017	Jun 2, 2017
JPL 1	YID 17-18A	Dec 15, 2017	Dec 18, 2017	Jun 01, 2018	Jun 07, 2018
ALARC 1	YID 17-18B	Jan 05, 2018	Jan 05, 2018	May 31, 2018	Jun 07, 2018
JPL 2	YID 17-18C	Jan 06, 2018	Jan 08, 2018	May 31, 2018	Jun 07, 2018
ALARC 2	YID 17-18D	Jan 24, 2018	Jan 29, 2018	June 01, 2018	Jun 07, 2018



Figure 1. Eddy Covariance systems used in field sites for studies. Shown are a typical deployment of three masts: net radiometer (left), eddy covariance main station (middle), and solar power supply (right).





Figure 2. Large Aperture Scintillometer used on Durum wheat sites in 2017-2018. Each setup consists of transmitter-receiver pairs, where a collimated beam of near infrared light is sent across a transect to detect scintillations due to changes in air refractive index. At the sampling wavelength, the scintillations are representative of sensible heat flux from the soil and crops below the light path.





Figure 3. Sentinel 2 image on April 6, 2018 of fields north of Yuma airport. Red colors indicate dense healthy green vegetation, yellow colors sparse vegetation, and blue-green colors bare soil or man-made surfaces.

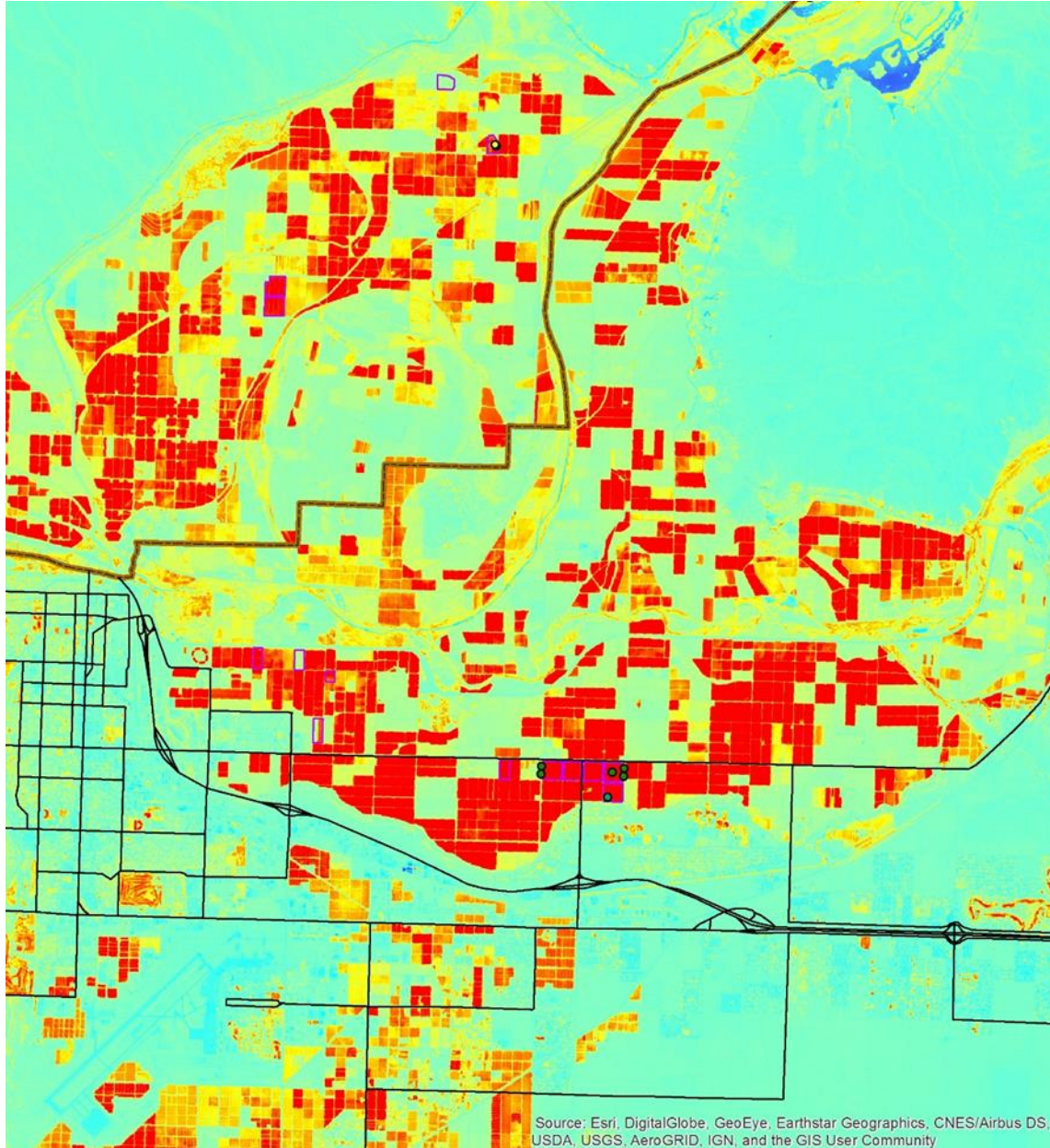




Figure 4. Daily and cumulative ET for Durum wheat in Yuma Irrigation District site in 2016-2017.

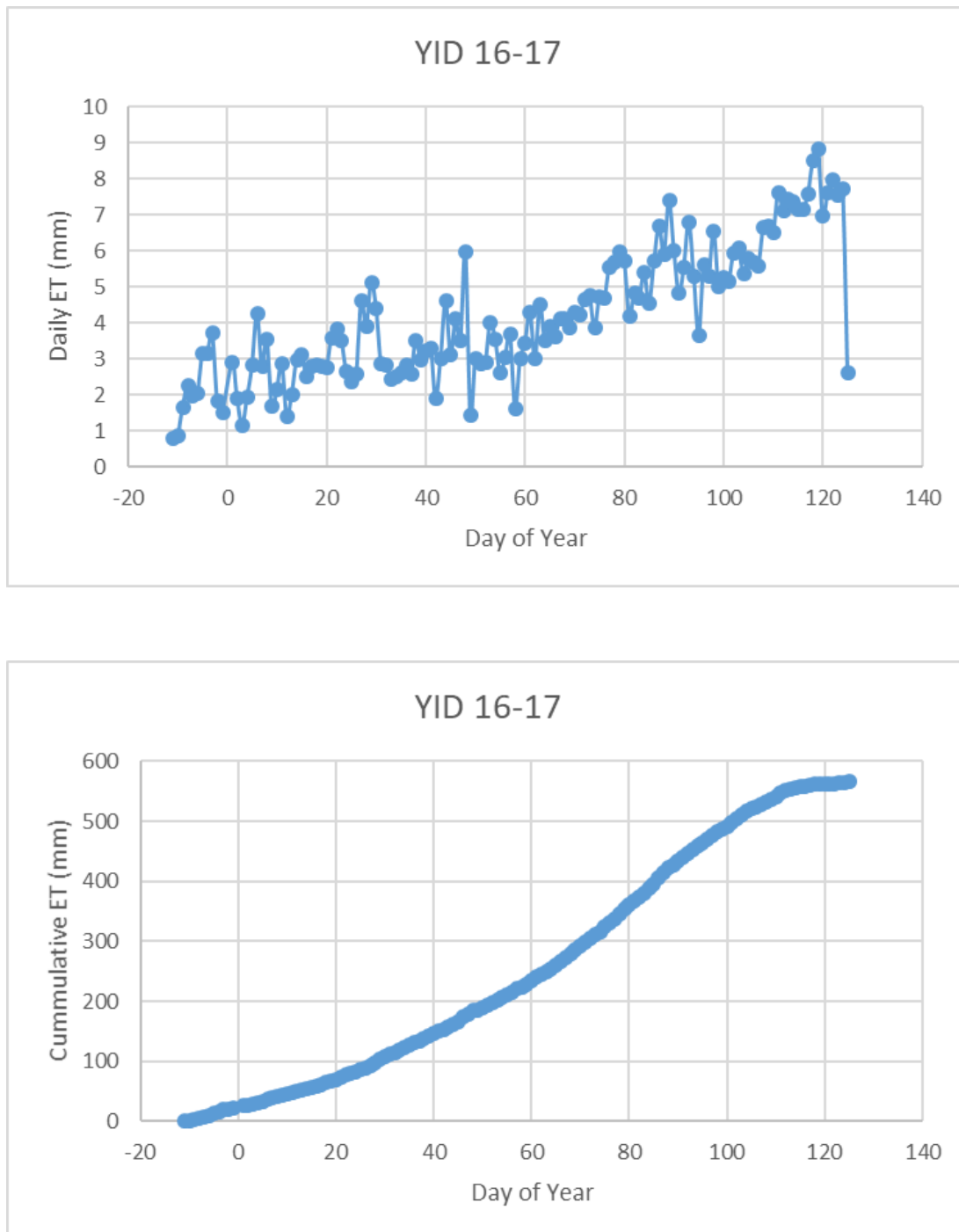




Figure 5. Daily and cumulative ET for Durum wheat in Yuma County Water Users Association site in 2017.

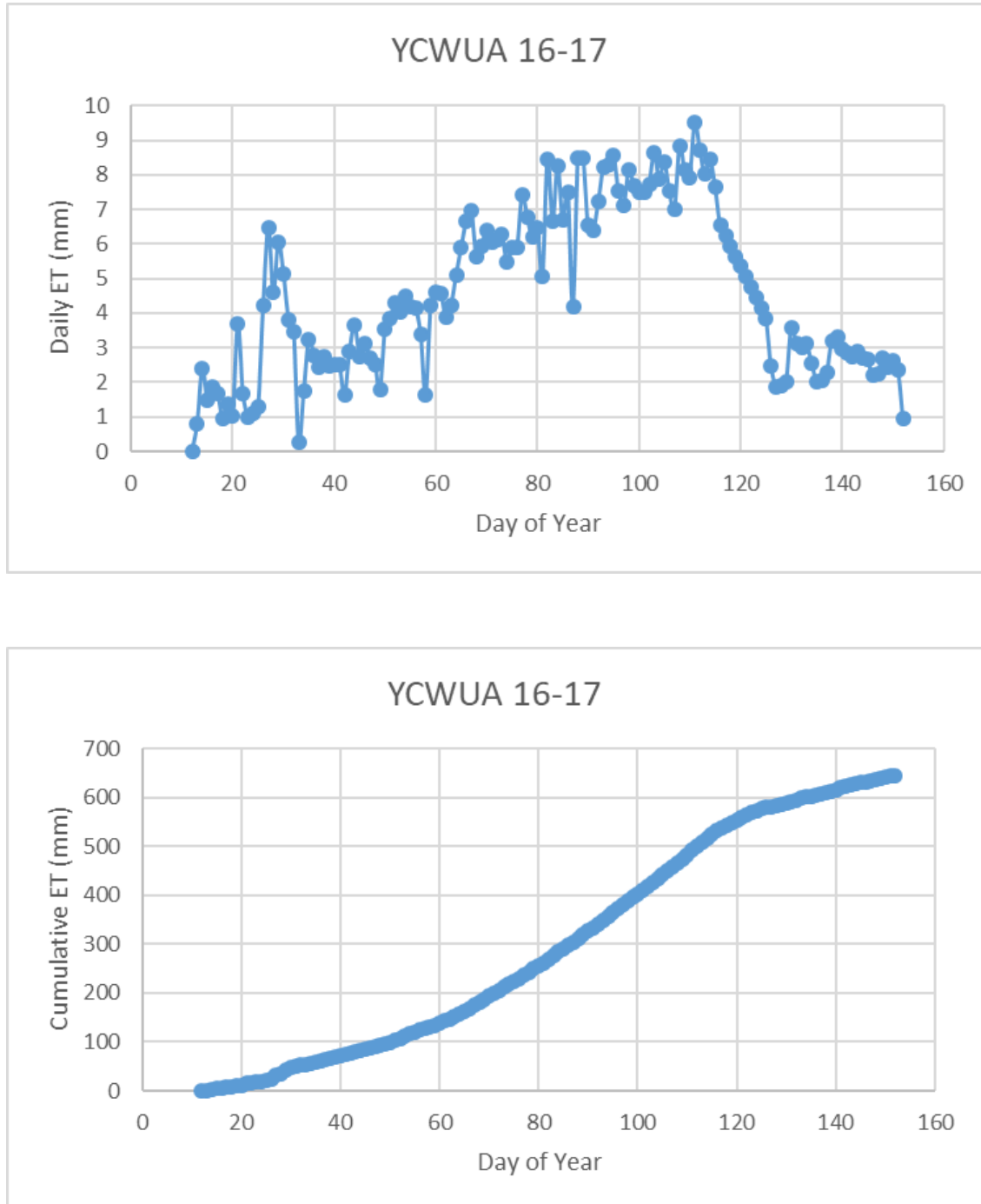




Figure 6. Daily and cumulative ET for Durum wheat in Yuma Irrigation District site A in 2017-2018.

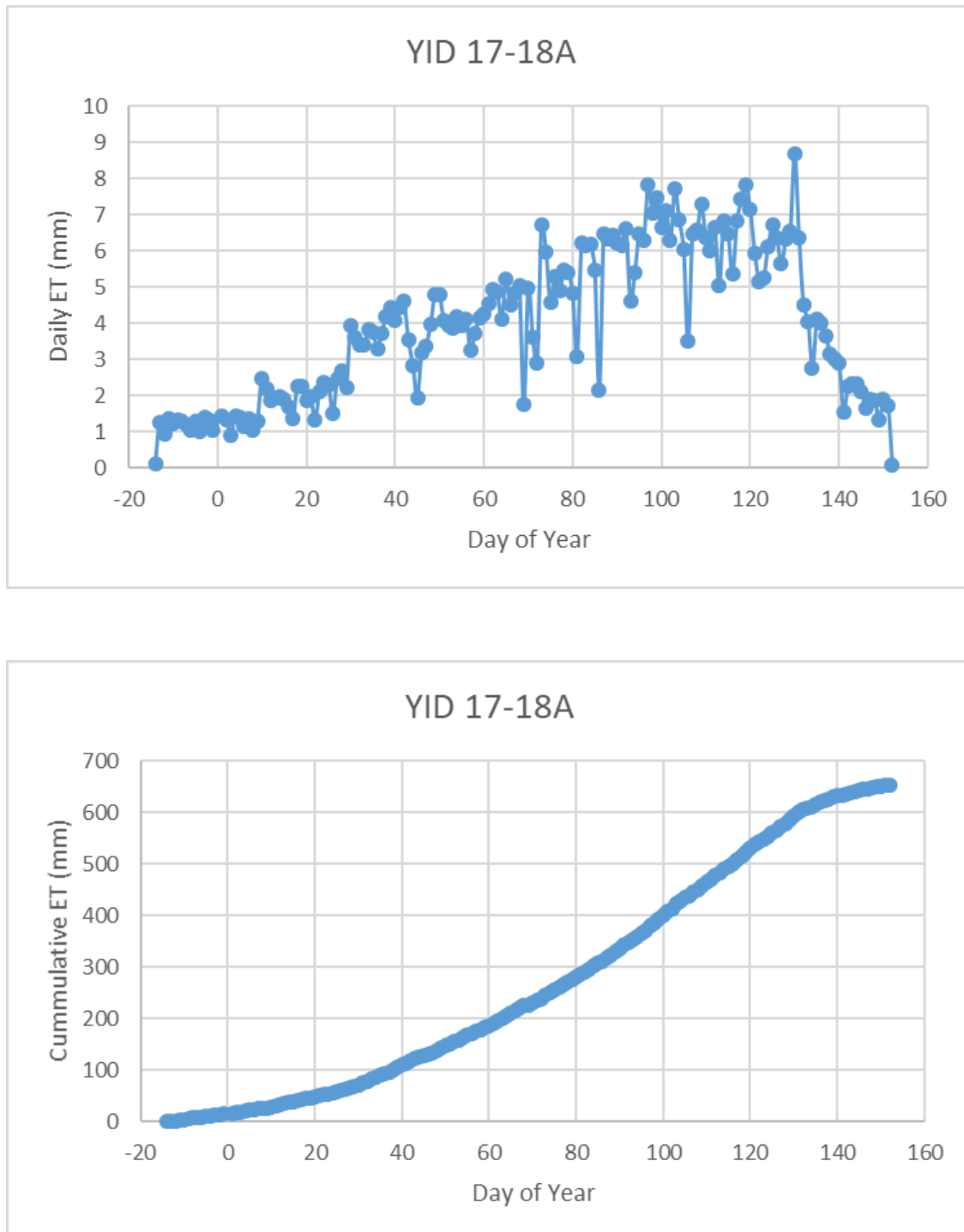




Figure 7. Daily and cumulative ET for Durum wheat in Yuma Irrigation District site B in 2018.

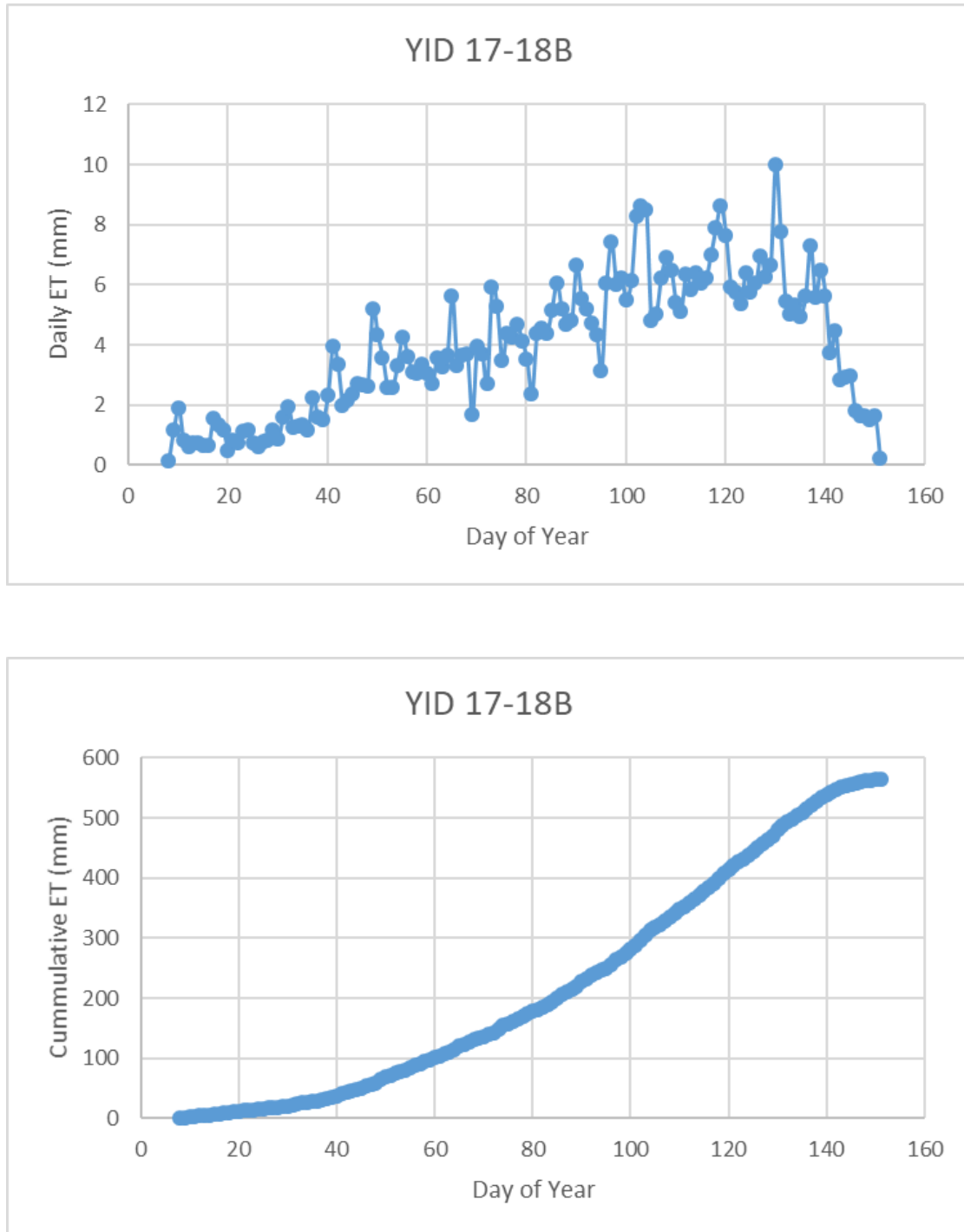




Figure 8. Daily and cumulative ET for Durum wheat in Yuma Irrigation District site C in 2018.

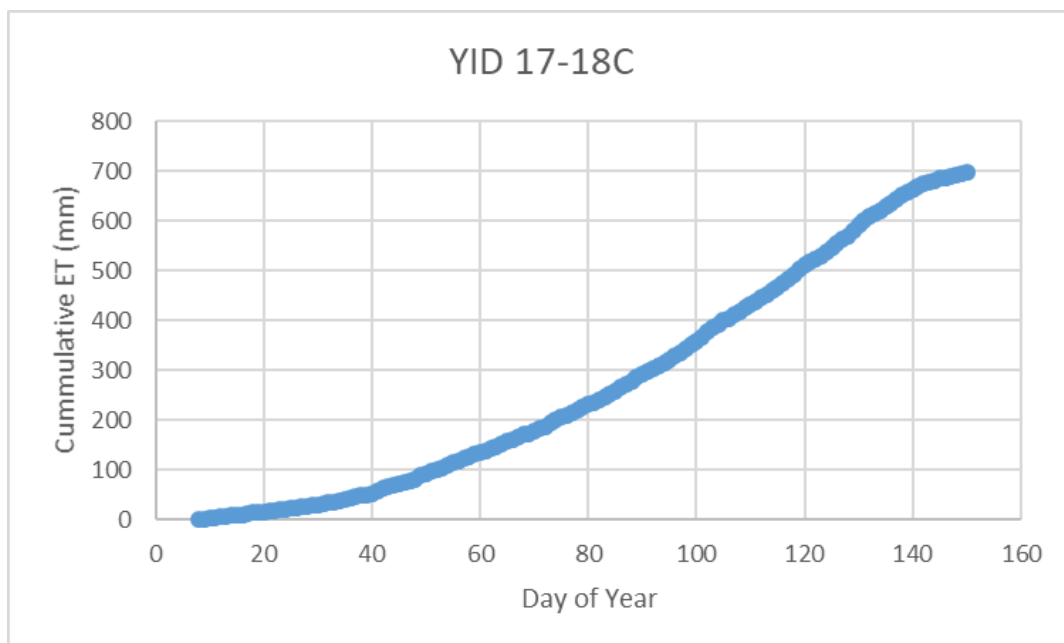
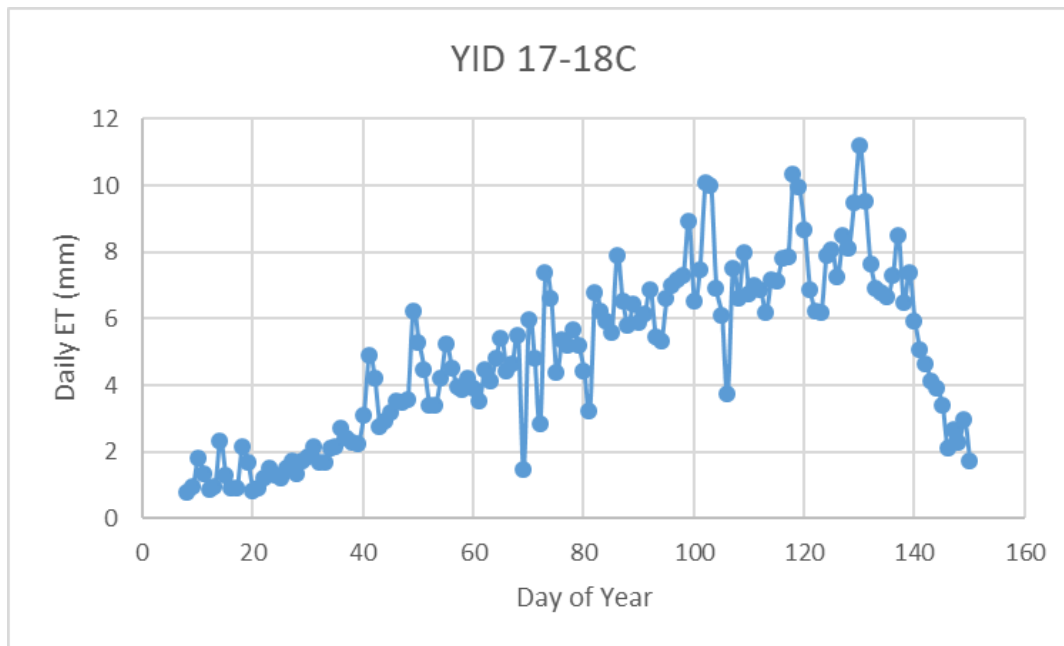




Figure 9. Daily and cumulative ET for Durum wheat in Yuma Irrigation District site D in 2018.

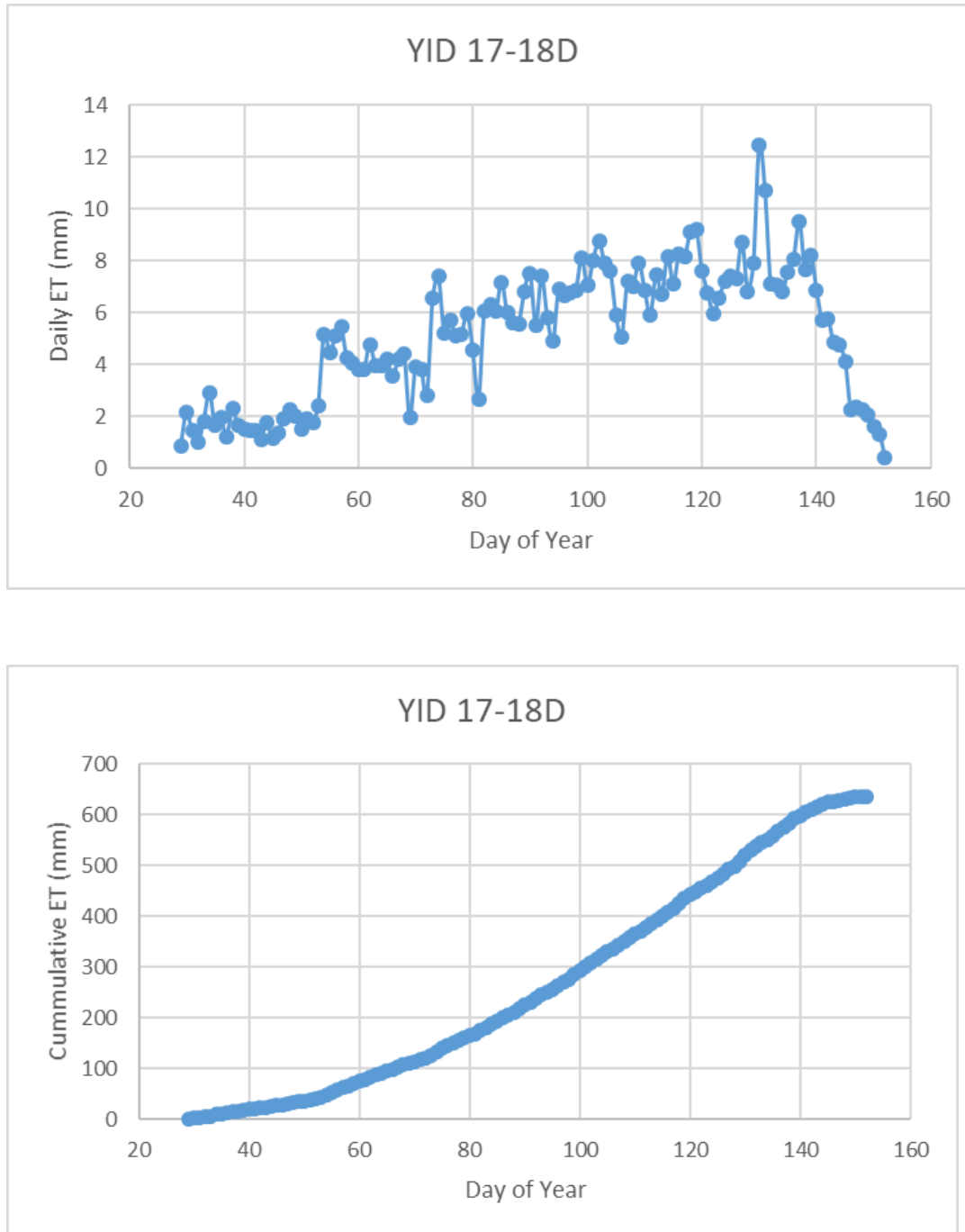




Figure 10. NDVI calculated from satellite imagery in 2017.

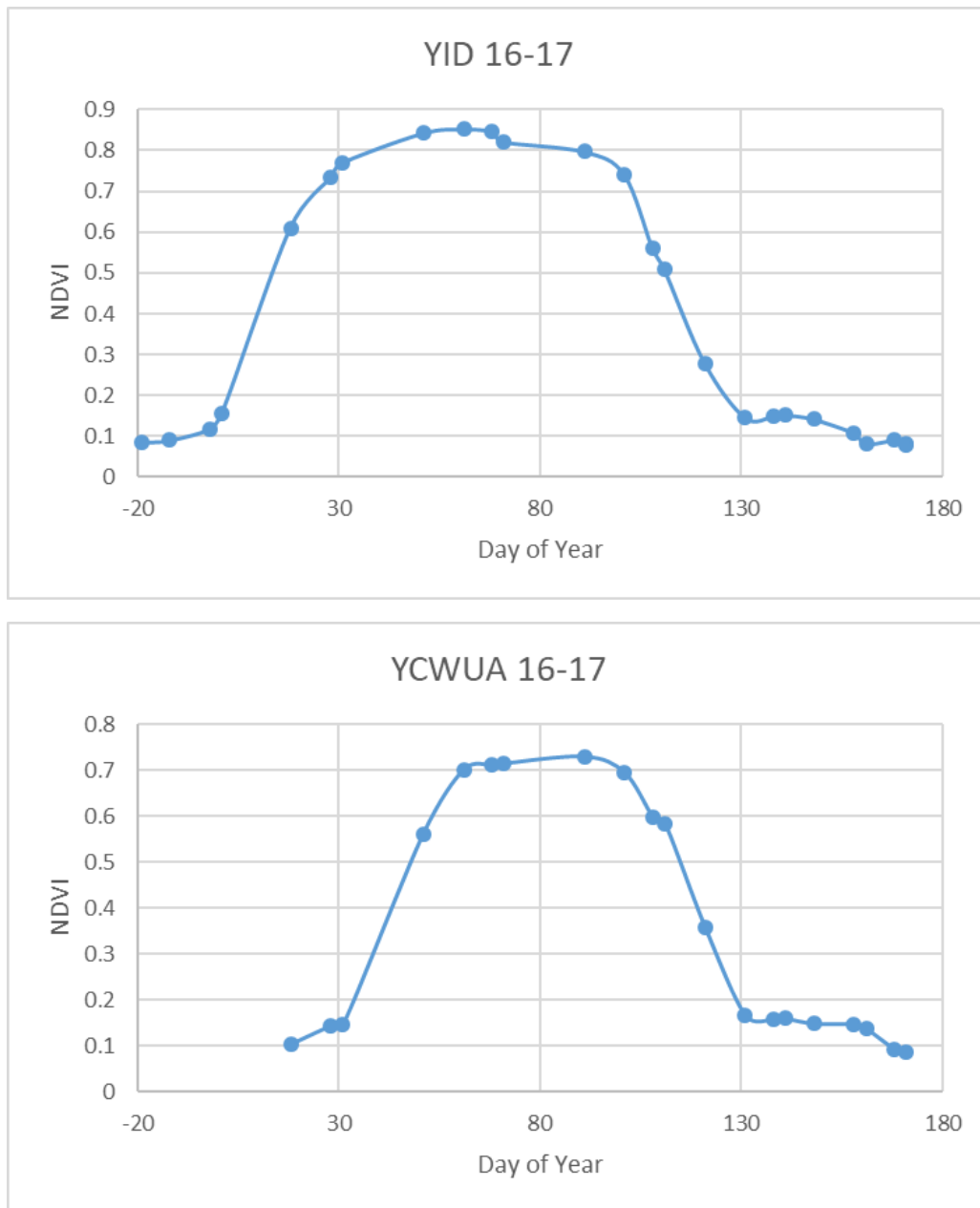




Figure 11. NDVI calculated from satellite imagery from four sites in 2018.

